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(54) Title: OPEN SENSOR DIAGNOSTIC SYSTEM FOR TEMPERATURE TRANSMITTER IN A PROCESS CONTROL SYSTEM
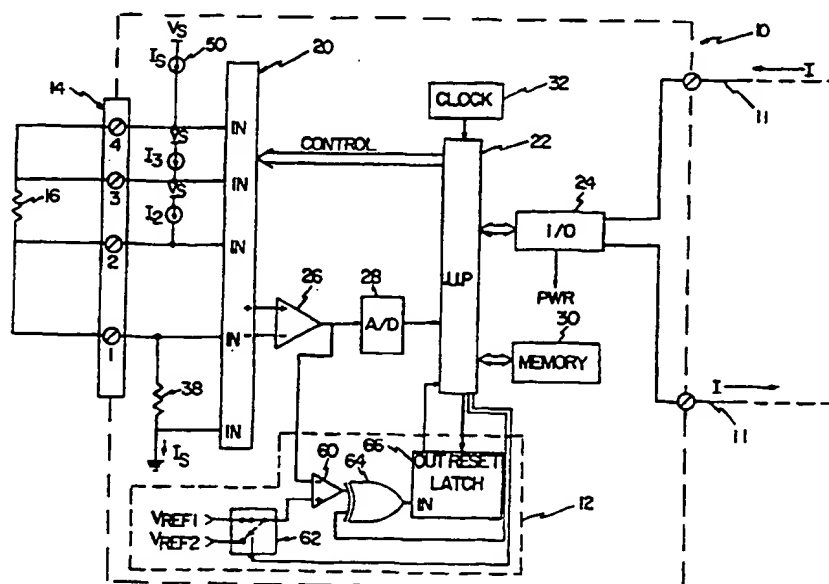
(57) Abstract

A temperature transmitter (10) in a process control system includes a temperature sensor (16, 18) which senses temperature and provides a sensor output related to sensed temperature. An analog-to-digital converter (28) coupled to the sensor output provides a digitized output related to the sensor output. A microprocessor (22) receives the digitized output, compensates the digitized output and provides a temperature output. Comparison circuitry (12) compares the sensor output to a first threshold V_{REF1} and provides an inhibit signal to the microprocessor (22) if the sensor is outside of the first threshold V_{REF1}.

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OPEN SENSOR DIAGNOSTIC SYSTEM FOR

TEMPERATURE TRANSMITTER IN A

PROCESS CONTROL SYSTEM

BACKGROUND OF THE INVENTION

5   The present invention relates to transmitters
used in process control systems. More specifically, the
present invention relates to a diagnostic technique for
identifying an open sensor condition in a temperature
transmitter.

10   Process control transmitters are used to
measure process parameters in a process control system.
Microprocessor-based transmitters include a sensor, an
analog-to-digital converter for converting an output
from a sensor into a digital format, a microprocessor
15   for compensating the digitized output and an output
circuit for transmitting the compensated output.
Typically, this transmission is over a process control
loop, such as a 4-20 mA current loop. One example
parameter is temperature which is sensed by measuring
20   the resistance of an RTD (Resistive Temperature Device),
also called a PRT (Platinum Resistance Thermometer)
sensor, or a voltage output of a thermocouple sensor.

        Temperature is measured by converting the
sensor output (resistance or voltage) to an output
25   indicative of temperature of the sensor. However, one
problem occurs when there is a loose connection between
the sensor and the input to the transmitter. The number
of sampling periods of the analog-to-digital conversion
is finite, and an intermittent open circuit can occur
30   during any of the sampling periods which is averaged out
over the rest of the sampling periods, an intermittent
connection can be hidden within a sampling period.
Thus, the system software cannot reliably detect an

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intermittent sensor connection. Any connection which is
open for a duration which is less than the sampling
period may go undetected by the microprocessor and lead
to inaccurate temperature readings.

5   SUMMARY OF THE INVENTION

A temperature transmitter in a process control
system includes a temperature sensor providing a sensor
output related to a sensed temperature and an analog-to-
digital converter coupled to the sensor output. The
10   analog-to-digital converter provides a digitized output
related to the sensor output. A microprocessor coupled
to the digitized output compensates the digitized output
and provides a temperature output. Comparison circuitry
compares the sensor output to a first threshold and
15   provides an inhibit signal to the microprocessor if the
sensor output is outside of the first threshold. In one
embodiment, the microprocessor recognizes the inhibit
signal as a fault and provides a warning output. A
second threshold can be used and the comparison
20   circuitry determines whether the sensor output is within
the boundaries of the first and second thresholds. The
response time of the comparison circuitry is faster than
the response time of the analog-to-digital converter.

BRIEF DESCRIPTION OF THE DRAWINGS

25   Figure 1A is a block diagram of a temperature
transmitter connected to measure temperature with an RTD
sensor, in accordance with one embodiment.

Figure 1B is a block diagram, like Figure 1A,
of a temperature transmitter connected to measure
30   temperature with a thermocouple sensor.

Figure 2 is a flow chart showing steps
performed by a microprocessor in accordance with one
embodiment of the invention.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1A is a block diagram of temperature transmitter 10 connected to measure temperature with an RTD sensor. Temperature transmitter 10 includes open
5   sensor diagnostic circuitry 12, in accordance with the invention. As described below, circuitry 12 monitors the temperature sensor of transmitter 10 and provides an output upon detection of an open sensor condition. Circuitry 12 is capable of detecting a momentary open
10   circuit condition having a duration which would typically not be detectable by transmitter 10. This information is used by transmitter 10 to diagnose an open circuit condition. For example, a temperature measurement obtained by transmitter 10 in which there is
15   a momentary open circuit can be ignored to avoid inaccurate temperature measurements.

Transmitter 10 couples to process control loop 11 which provides power to transmitter 10 and over which information is transmitted and received. Transmitter 10
20   includes terminal block 14 having terminals 1 through 4 for coupling to, for example, an RTD temperature sensor 16 or a thermocouple temperature sensor 18 (shown in Figure 1B). Figure 1A shows the electrical connections to RTD 16. Sensor 16 (and sensor 18) can be either
25   internal or external to transmitter 10. Transmitter 10 includes multiplexer 20 controlled by microprocessor 22 which is coupled to control loop 11 through input/output (I/O) circuitry 24. Multiplexer 20 multiplexes appropriate sets of analog signals, including signals
30   from terminals 1 through 4, to positive and negative inputs of differential amplifier 26, which connects to high accuracy A/D converter 28. In one embodiment, converter 28 has an accuracy of 17 bits and a conversion rate of 14 samples/second. Memory 30 stores

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instructions and information for microprocessor 22, which operates at a speed determined by clock 32. Multiplexer 20 selectively connects input pairs to the positive and negative inputs of differential amplifier 5   26. A reference resistance R_{REF} 38 couples to multiplexer 20 and is connected in series with RTD 16.

In operation, transmitter 10 measures temperature of sensor 16 and transmits a representation of temperature over control loop 11. Transmitter 10 10   employs the following equation to compute the major value of temperature of RTD 16:

$$R_{INPUT} = \frac{V_{RINPUT}}{V_{RREF}} (R_{REFNOM}) \qquad\qquad \text{Equation 1}$$

15   where:

R_{REFNOM} =   the nominal resistance of the reference resistance in ohms, and/or stored in memory 30;

V_{RINPUT} =   voltage drop across the input; and

20   V_{RREF} =   voltage drop across R_{REF}.

Current source 50 provides current I_s through sensor 16 (via terminals 1 and 4) and reference resistor 38. Microprocessor 22 measures the voltage drop (V_{RINPUT}) across RTD 16 between terminals 2 and 3, and the voltage 25   drop (V_{RREF}) across resistor 38 with MUX 20. R_{REFNOM} is a calculation constant and is retrieved from memory 30. In a four-wire resistance measurement such as this, the voltage drop across the connections to terminals 2 and 3 is largely eliminated, since substantially all the 30   current flows between terminals 1 and 4, and has little impact on the accuracy of the measurement. R_{INPUT} is converted to temperature units with a look-up table or suitable equation stored in memory 30.

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Figure 1B shows transmitter 10 connected to measure temperature with thermocouple sensor 18 which creates a voltage $V_{TCINPUT}$ across terminals 1 and 2. Multiplexer 20 couples inputs of differential amplifier

5   26 to terminals 2 and 1.   Figure 1B shows a voltage reference (V_{TCREF}) 36 coupled to MUX 20 and current source 50.

Transmitter 10 measures the temperature of thermocouple sensor 18 by determining the thermocouple

10   voltage V_{TC} with the following equation:

$$V_{TC} = \frac{V_{TCINPUT}}{V_{TCREF}} (V_{TCREFNOM}) \qquad \text{Equation 2}$$

where:

15    $V_{TCINPUT}$ =   the measured voltage across terminals 1 and 2 of terminal block 14 sensed by amplifier 26;

V_{TCREF} =   the   measured   voltage   generated   by voltage   reference   36   as   sensed   by

20   amplifier 26;

$V_{TCREFNOM}$ =   a nominal value of voltage reference 36 stored in memory 30;

However, the junction between two dissimilar metals formed at terminal 1 introduces a cold junction

25   error voltage proportional to the temperature of the junction. The error voltage is sensed by measuring the temperature of the junction at terminal 1 based upon the resistance of a PRT (Platinum Resistance Thermometer) sensor 34 and subsequently using a standard equation or

30   look-up table to determine the cold junction error voltage. Resistance R_{CJCPRT} of sensor 34 is measured using Equation 1 by applying a current I_s from with current source 50. Microprocessor 20 computes V_{TC} according to Equation 2, then effectively subtracts

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R_{CJCFRT} from V_{TC} using an appropriate look-up table or equation. Then the resulting compensated temperature of sensor 18 is coupled to loop 11 via output circuitry 24.

In the embodiments of Figures 1A and 1B, open sensor diagnostic circuitry 12 and current sources I_S, I_2 and I_3 in accordance with the invention are shown. Open sensor diagnostic circuitry 12 includes comparator 60 having an inverting input coupled to the output of differential amplifier 26 or to the outputs of multiplexer 20, and a non-inverting input coupled to switch 62. Switch 62 selectively couples the non-inverting input of comparator 60 to voltage reference V_{REF1} or V_{REF2} under control of microprocessor 22. The output of comparator 60 is provided to exclusive OR (XOR) gate 64. A second input to exclusive OR gate 64 is provided by microprocessor 22. The output of exclusive OR gate 64 is provided to an input of latch 66. Latch 66 also includes a reset input connected to microprocessor 22 and an output connected to microprocessor 22.

In operation, an open sensor condition will cause the output of amplifier 26 or the output of multiplexer 20 to go outside of its normal operating range due to current applied from current sources I_2 or I_3, either too high or too low. The direction of the output variance depends upon the configuration of the input circuitry as connected through multiplexer 20. Sources I_2 and I_3 may be, for example, pull-up or pull-down resistors. Microprocessor 22 controls the connection between V_{REF1} and V_{REF2} and comparator 60. Further, microprocessor 22 can invert the output of comparator 60 using exclusive OR gate 64.

Depending upon the type of reading being taken through multiplexer 20 and the direction of current

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sources I_s, I_2 and I_3, microprocessor 22 is programmed to recognize a reading which is outside of a normal operating range.   For example,   in   Equation   1 microprocessor 22 can monitor the measurements V_{RINPUT} or

5   V_{RREF}.   Similarly,   microprocessor   22   can   monitor   the voltage across sensor terminals 1 and 2 to sense if sensor lead 2 is open, or can monitor voltage across sensor terminals 1 and 3 to sense if sensor lead 3 is open.   Similarly, microprocessor 22 can monitor $V_{TCINPUT}$

10   or V_{TCREF}.   For example, if, for any one sensor lead, an open connection would cause the output of amplifier 26 to go above a normal operating range, microprocessor 22 operates switch 62 to connect the appropriate reference level to comparator 60.   This would result in a sensor

15   open circuit condition causing the output of comparator 60 to go to a logic LOW.   In one embodiment, the input to exclusive OR gate 64 is set so that the exclusive OR gate inverts the signal to a HIGH level to signal microprocessor 22 of the sensor failure.   In one

20   embodiment, microprocessor 22 also controls current sources I_2 and I_3 and selectively couples them to terminals 2 and 3, respectively, during a diagnostic cycle.

        Latch 66 is connected to the output of

25   exclusive OR gate 64 and is used to latch the output of exclusive OR gate 64.   For example, if the open sensor or open sensor lead is a momentary "glitch" which occurs during a period which is less than the sampling period of analog-to-digital converter 28, the sensor failure

30   signal provided by gate 64 is latched in latch 66 and provided   to   microprocessor   22.   This   signals microprocessor 22 that there was an open sensor condition   during   the   sampling   time   period.

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Microprocessor 22 provides a reset signal to latch 66 which resets the output of latch 66.

Figure 2 is a flow chart 100 showing operation of microprocessor 22 in the embodiment of Figure 1A.

5   Operation of microprocessor 22 is in accordance with instructions stored in memory 30. Microprocessor 22 recalls R_{REFNOM} from memory 30 at flow chart block 102. At block 104, microprocessor 22 controls switch 62 to connect the non-inverting input of comparator 60 to the

10   voltage reference V_{REF1}. Next, microprocessor 22 provides a high input to exclusive OR gate 64. Microprocessor 22 controls multiplexer 20 to connect terminals 2 and 3 of terminal block 14 to the inputs of differential amplifier 26 at flow chart block 108. This

15   allows measurement of V_{RINPUT}. At control block 110, microprocessor 22 resets latch 66. V_{RINPUT} is measured at block 112 by microprocessor 22 using analog-to-digital converter 28. After obtaining V_{RINPUT}, microprocessor 22 observes the output of latch 66 at block 114. A HIGH

20   output from latch 66 indicates that the voltage across terminals 2 and 3 of terminal block 14 exceeded a predetermined maximum determined by V_{REF1} during analog-to-digital conversion by converter 28. If latch 66 provides a HIGH output, control is passed to block 116,

25   otherwise control is passed to block 118 where the measurement of V_{RREF} begins. V_{REF2} is connected to comparator 60 by microprocessor 22 using switch 62. At block 120, a logic LOW is provided to an input of exclusive OR gate 64.

30   Next, at block 122, microprocessor 22 controls multiplexer 20 to measure V_{REF} which is the voltage across resistor 38. At block 124, latch 66 is reset by microprocessor 22 and microprocessor 22 reads V_{REF} from analog-to-digital converter 28 at block 126. After

reading V_{REF}, microprocessor 22 observes the output of latch 66 at block 128. If the latch output is HIGH, microprocessor 22 determines that an error has occurred and control is passed to block 116. If there is no

5   error, control moves to block 130 where R_{INPUT} is calculated in accordance with Equation 1. At block 132, R_{INPUT} is converted to temperature by means of an algorithm or a look-up table stored in memory 30 and its value is transmitted at block 134. Following

10 transmission, the process is repeated and control is returned to block 102. In a similar manner also, diagnostics are done periodically on leads 2 and 3 also using I_2 and I_3 currents. Typically, all leads are scanned every time a total sensor update occurs.

15   If the output of latch 66 indicates the occurrence of an error, control is passed to block 116. At block 116, the value obtained from analog-to-digital converter 28 is discarded. At block 136, microprocessor 22 transmits a signal over loop 11 using IO circuitry 24

20 which indicates the occurrence of an error. Control is then returned to block 102 and the process is repeated.

            A monitor in the control room can monitor operation of transmitter 10 and detect error signals sent from transmitter 10. If transmitter 10 is

25 repeatedly sending error signals, the monitor in the control room can use this information to alert an operator that there is an open sensor condition at transmitter 10. Additionally, if errors occur only periodically, the operator can be notified that there

30 may be an impending problem with the sensor in transmitter 10. Intermittent errors can also be latched in the microprocessor software to provide a continuous alarm.

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The loose sensor connection diagnostic for the
embodiment of Figure 1B operates similar to that
described above for Figure 1A, and Equations 2 and 3 are
employed to determine temperature.

5   It will be recognized by those skilled in the
art that the circuitry set forth in the present
invention may be modified as appropriate. For example,
multiple circuits could be employed to simultaneously
detect if the output voltage is above or below certain
10   thresholds. Further, more than two voltage references
may be used. In another example, the voltage reference
could be controlled by the microprocessor using a
digital-to-analog converter such that the microprocessor
can independently select the voltage threshold.

15   Although the present invention has been
described with reference to preferred embodiments,
workers skilled in the art will recognize that changes
may be made in form and detail without departing from
the spirit and scope of the invention. For example, the
20   comparison circuit can be connected at any appropriate
location, such as between the multiplexer and the
differential amplifier.

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WHAT IS CLAIMED IS:

1.   A temperature transmitter in a process control
system, comprising:

> a temperature sensor sensing a temperature
>   and providing a sensor output related to
>   a sensed temperature;
>
> an A/D converter coupled to the sensor output
>   providing a digitized output related to
>   the sensor output;
>
> a microprocessor coupled to the digitized
>   output which compensates and processes
>   the digitized output and provides a
>   temperature output; and
>
> comparison circuitry which compares the
>   sensor output to a first threshold and
>   provides an inhibit signal to the
>   microprocessor if the sensor output is
>   outside of the first threshold.

2.   The temperature transmitter of claim 1 wherein
the sensor output includes a plurality of sensor leads
which are individually coupled to the comparison
circuitry through a multiplexer.

3.   The temperature transmitter of claim 1 wherein
the comparison circuitry compares the sensor output to
a second threshold and provides the inhibit signal if
the sensor output is outside the first and second
thresholds.

4.   The temperature transmitter of claim 2
including a switch connected to the first and second
thresholds and an input to the comparison circuitry
connecting the first or second thresholds to the
comparison circuitry input in response to a control
signal from the microprocessor.

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5.   The temperature transmitter of claim 1 wherein
the microprocessor is coupled to the inhibit signal and
the inhibit signal inhibits the temperature output.

6.   The temperature transmitter of claim 1 wherein
the comparison circuitry has a faster response time than
a response time of the A/D converter.

7.   The temperature transmitter of claim 1 wherein
the comparison circuitry includes a polarity control
input for selectively inverting the inhibit output.

8.   The temperature transmitter of claim 7 wherein
the polarity control input is coupled to the
microprocessor.

9.   The temperature transmitter of claim 1
including output circuitry coupled to a two-wire process
control loop which transmits the temperature output on
the process control loop.

10.   The temperature transmitter of claim 1 wherein
the sensor is an RTD.

11.   The temperature transmitter of claim 1 wherein
the sensor is a thermocouple.

12.   The temperature transmitter of claim 1 wherein
the microprocessor is coupled to the inhibit signal and
responsively provides a diagnostic output.

13.   A method of measuring temperature of a process
in a process control system, comprising the steps of:

        obtaining a sensor input related to
            temperature of the process;

        providing a digitized output related to the
            sensor output;

        compensating the digitized output and
            providing a compensated output
            indicative of temperature of the
            process;

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comparing the first sensor input with a
threshold; and

providing an error signal based upon the
comparison.

14.   The method of claim 13 including inhibiting
the compensated output in response to the error signal.

15.   The method of claim 13 including:

comparing the sensor input with a second
threshold; and

providing the error signal based upon the
comparison with the second threshold.

16.   The method of claim 13 including adjusting the
first threshold based upon a type of sensor which
provides the sensor input.

17.   The method of claim 13 wherein the step of
comparing is faster than the step of providing the
digitized output.

18.   The method of claim 13 including transmitting
the compensated output over a two-wire process control
loop.

19.   The method of claim 13 including selectively
inverting the polarity of the error signal.

20.   The method of claim 13 wherein the sensor
input includes a plurality of sensor leads, the method
including individually comparing a sensor input from
each sensor lead with a threshold.

21.   The method of claim 13 including providing a
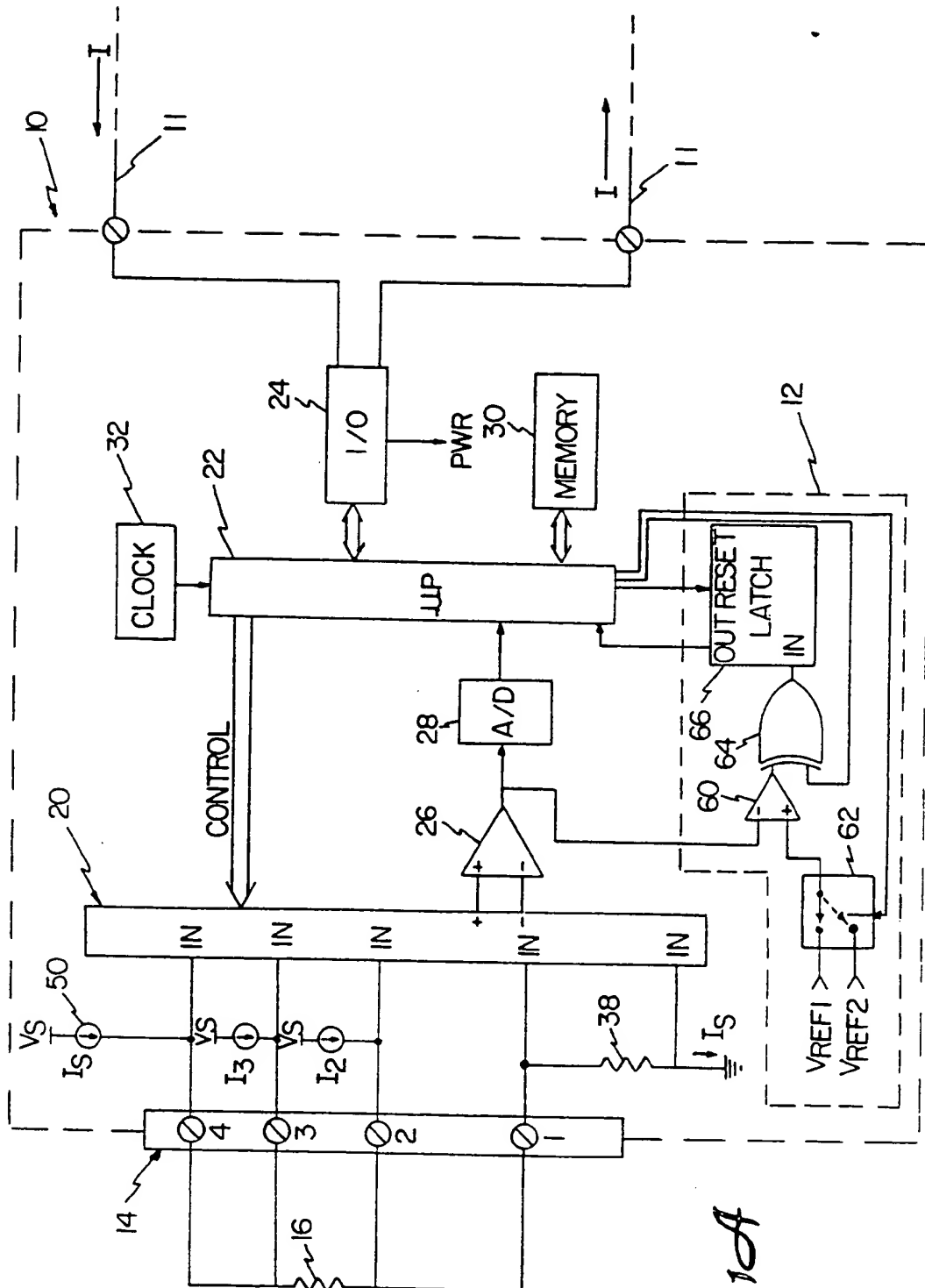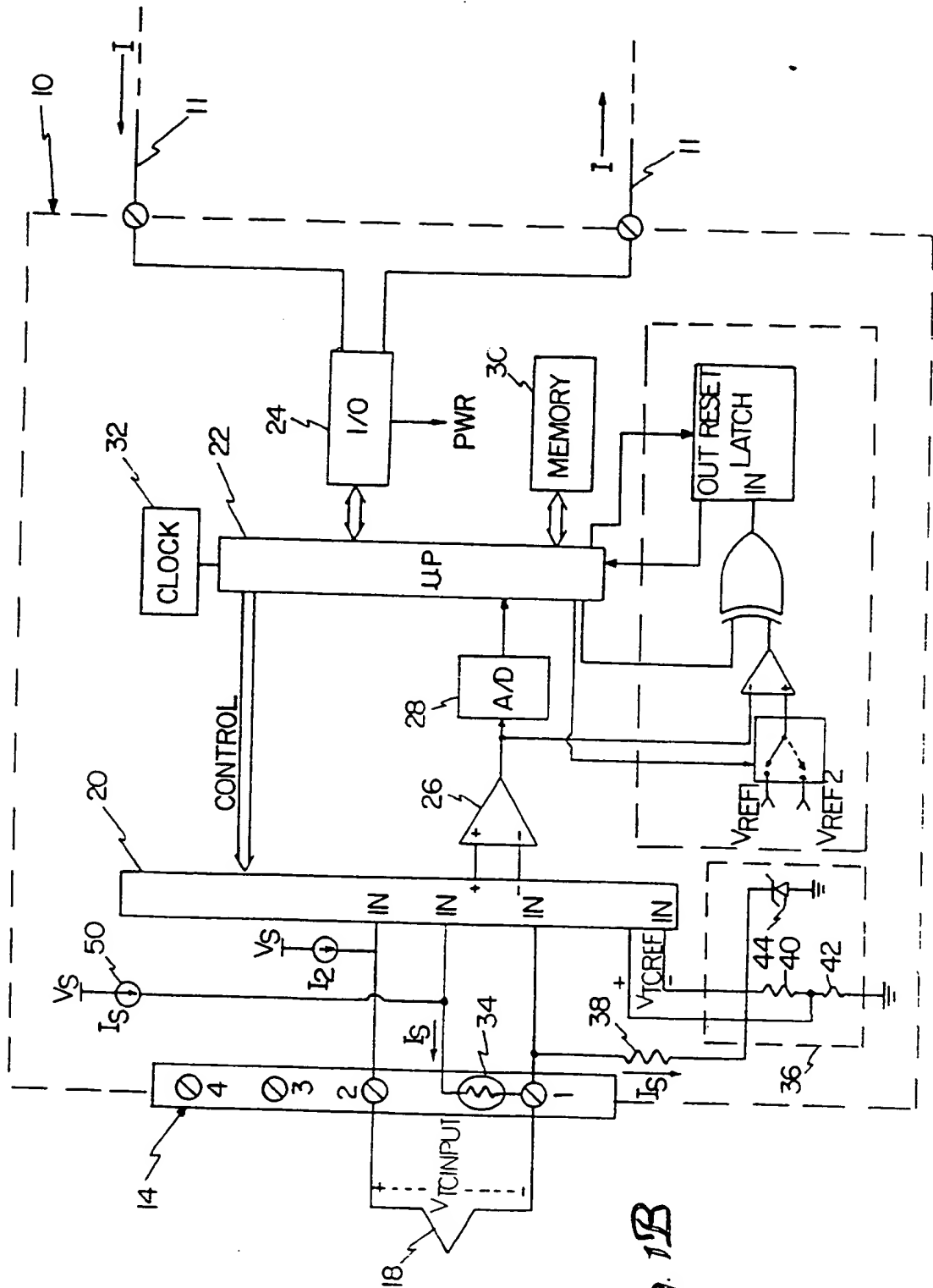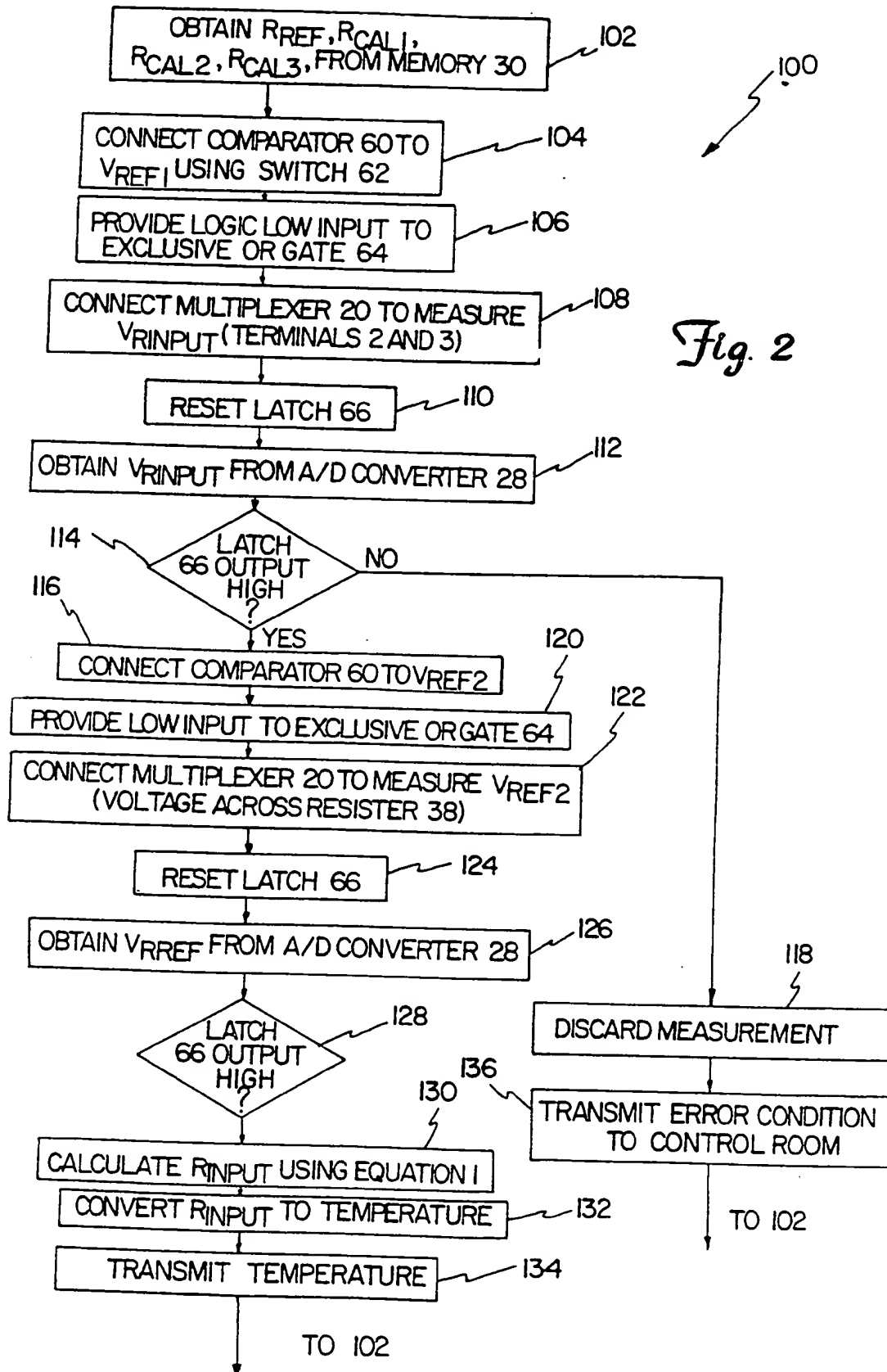diagnostic output in response to the error signal.

Fig. 1A

Fig. 1B

OBTAIN R$_{REF}$,R$_{CAL 1}$, R$_{CAL 2}$, R$_{CAL 3}$, FROM MEMORY 30 —102

100

CONNECT COMPARATOR 60 TO V$_{REF1}$ USING SWITCH 62 —104

PROVIDE LOGIC LOW INPUT TO EXCLUSIVE OR GATE 64 —106

CONNECT MULTIPLEXER 20 TO MEASURE V$_{RINPUT}$ (TERMINALS 2 AND 3) —108

Fig. 2

RESET LATCH 66 —110

OBTAIN V$_{RINPUT}$ FROM A/D CONVERTER 28 —112

114 — LATCH 66 OUTPUT HIGH ? — NO

116 — YES

CONNECT COMPARATOR 60 TO V$_{REF2}$ 120

PROVIDE LOW INPUT TO EXCLUSIVE OR GATE 64   122

CONNECT MULTIPLEXER 20 TO MEASURE V$_{REF2}$ (VOLTAGE ACROSS RESISTER 38)

RESET LATCH 66 —124

OBTAIN V$_{RREF}$ FROM A/D CONVERTER 28 —126

LATCH 66 OUTPUT HIGH ? —128

136

130

CALCULATE R$_{INPUT}$ USING EQUATION 1

CONVERT R$_{INPUT}$ TO TEMPERATURE —132

TRANSMIT TEMPERATURE —134

TO 102

118

DISCARD MEASUREMENT

TRANSMIT ERROR CONDITION TO CONTROL ROOM

TO 102

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G01K7/02   G01K15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,4 475 823 (STONE W PORTER) 9 October 1984 see column 3, line 50 - column 4, line 66 ---	1,10,12, 13,16
A	US,A,4 841 286 (KUMMER KARL T) 20 June 1989 see column 4, line 3 - line 63 ---	1,11-13, 16,21
A	US,A,4 279 151 (ANDERSON JACK A) 21 July 1981 see the whole document -----	1,9, 11-13, 16,18,21

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

22 August 1996

Date of mailing of the international search report

1 3. 09. 96

Form PCT.ISA/210 (second sheet) (July 1992)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4475823	09-10-84	NONE	
US-A-4841286	20-06-89	NONE	
US-A-4279151	21-07-81	NONE	